

AN EXPERIMENTAL STUDY ON THE CHARACTERISTICS OF DI-CI ENGINE WITH THE PREHEATED WASTE COOKING OIL METHYL ESTER

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ABSTRACT

In the current scenario the driving forces for the research work on the alternative fuels are exhaustion of conventional fossil fuels, high petroleum diesel prices and increased environmental pollution. Biodiesel is one of the promising alternative fuels for petroleum diesel. Generally biodiesel is produced from seed oils and when they are produced from vegetable seed oils, it leads to scarcity of food oils. In such case the biodiesel produced from waste cooking oil (waste cooking oil methyl ester-WCOME) would be one of the best alternatives to the petroleum diesel. The higher viscosity of WCOME is one of the constraints to use directly in a diesel engine. Hence the present work reports the use of preheated WCOME in DI-CI diesel engine. The engine performance and emission characteristics were studied with preheated WCOME and compared them with no preheated WCOME and standard petroleum diesel characteristics. The results revealed that the considerable increase in brake thermal efficiency and decreased brake specific fuel consumption compared to without preheating. Improved emission characteristic was also obtained with preheated WCOME compared to without preheating. However, all the characteristics with preheated WCOME are slightly lower than petroleum diesel, but are very close to them. Hence preheated WCOME can be used in existing DI-CI engine to obtain similar characteristics as that of diesel without any modifications in the engine.

KEYWORDS: DI-CI Engine, Waste Cooking, Oil Methyl Ester, Petroleum Diesel, Preheated Fuel & Engine Characteristics

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INTRODUCTION

Increasing industrialization and rapid rise in the number of vehicles in the transportation sector increases the dependency of fossil fuels mainly on petroleum diesel. The availability of fossil fuels is also limited to very few countries across the world. The economic growth of countries which have no fuel resources is greatly affected due dependency on other countries. The other side emissions produced by fossil fuels are a major challenge for the world. To reduce emissions and dependency on fossil fuels has led the research towards development of new substitute and renewable fuels. Biodiesel (methyl or ethyl esters) seems to be alternative to the existing fossil fuels. Many of the researchers worked with biodiesel produced from vegetable oil as a substitute and successfully run the diesel engines without any modifications and obtained results closer to that of petroleum diesel. When vegetable oils are used for development, biodiesel, there may be a scarcity for food oils in the market. To avoid this, used cooking oil can be considered for development of biodiesel. Few researchers carried their work with biodiesel produced from used cooking oil and obtained results close to petroleum diesel. They reported higher viscosity is

the reason for low brake thermal efficiency and higher brake specific fuel consumption with waste cooking oil biodiesel. Hence, in the present work an attempt has made to reduce the viscosity of waste cooking oil biodiesel by preheating. Viscosity of fuel is greatly reduced when preheated. Hence, in the present work diesel engine characteristics are studied with preheated waste cooking oil, biodiesel and compared the results with standard petroleum diesel fuel and waste cooking oil biodiesel without preheating.

LITERATURE REVIEW

Tippayawong et al. [1] studied the effect of fuel inlet temperature on the performance and emissions of the engine for soybean and palm oil at different engine speeds. They observed that for both vegetable oils, brake specific fuel consumption did not change much for given engine speed. In the case of soybean oil increasing temperature tended to reduce NO_x . Elevated fuel inlet temperatures proved not to have any significant effect on engine fuel consumption. Agrawal et al. [2] investigated the performance characteristics of a 4-s single cylinder diesel engine fuelled by preheated *Jatropha* biodiesel. They reported that the BSFC of preheated *Jatropha* oil was higher than that of diesel fuel but lower than without preheated *Jatropha* oil. Moreover, the thermal efficiency of preheated *Jatropha* oil was lower than the diesel fuel, but slightly higher than without preheated oil.

Murat Karabektas et. al. [3] conducted experiments in full load conditions on a single cylinder, four-stroke, direct injection diesel engine. Before supplied to the engine, Cotton seed methyl ester (COME) was preheated to 30°C, 60°C, 90°C and 120°C. They evaluated the brake power and brake thermal efficiency (BTE) together with CO and NO_x emissions. From the results it was revealed that preheating Cotton seed methyl ester up to 90°C shown favourable effects on the BTE and CO emissions but causes higher NO_x emissions. Ch. Satyanarayana and P. V. Rao [4] reduced the viscosity of fuel by preheating and studied DI Diesel engine characteristics. They observed with preheated *Pongamia* Biodiesel admission decrease in premixed combustion and increase in diffused combustion. Their results showed the improved performance characteristics and reduced emissions, including NO_x with preheated biodiesel. Lower CO_2 , unburned HC and smoke emissions compared to the diesel fuel had been reported with preheated crude sunflower oil by Canaki et al. [5]

Sagar Pramodrao Kadu and Rajendra H. Sarda[6] conducted experimental investigations on the use of *Karanja* oil with preheated condition as fuel in the engine. Different preheated temperatures like 30°C, 70°C and 100°C was used for the study and the results were compared with diesel fuel at 30°C. They observed significant improvement in engine characteristics were noticed with the preheated *Karanja* oil. M. Pugazhivadivu and G. Sankaranarayana [8] carried investigations on 3.7kW constant speed diesel engine with preheated *Mahua* oil as fuel and improved engine performance decreased emissions with preheating *Mahua* oil were observed.

M. Martin and D. Prithviraj [9] studied engine characteristics with the preheated cotton seed oil. Viscosity of cotton seed oil at various temperatures was also analysed and used as fuel in compression ignition engine in the preheated condition. All the engine characteristics at various loads were calculated and remarkable improvement in the performance of the engine is noticed as the viscosity of the oil is reduced. Significant reduction in the exhaust gas temperature, smoke, CO and HC in the exhaust emissions were also noticed in their study. R. Ragu et al. [10] investigated on the characteristics of 4.4 kW Kirloskar Diesel engine with the preheated rice bran oil. With the help of heat exchanger using the exhaust gases rice bran oil was preheated. From the study they found that the preheated Rice bran oil exhibits improved engine

characteristics in terms of performance and emissions compared to Rice bran oil without preheating.

Augustine et al. [11] revealed lower CO, unburned HC and smoke produced were lower compared to diesel fuel when preheated cottonseed oil methyl ester was used as fuel in the direct injection diesel engine. This was attributed to the higher O₂ content of biodiesel which could improve the combustion process and heating process decreases the viscosity of biodiesel, thus improves the oxidation of biodiesel in the cylinder. However, preheated cottonseed oil methyl ester yields higher NO_x emission at all loads than that of diesel fuel. Hossain and Davies [12] studied the effects of Jatropha and Kranja oils in diesel engine. CO and CO₂ emissions were almost the same for all fuels at lower loads and at higher loads, diesel emissions were lower compared to Jatropha and Kranja oils. However, NO emission was higher for both fuels while O₂ produced was lower than that of diesel fuel.

MATERIALS AND METHODS

Fuel

The method adopted for the preparation of Waste cooking oil methyl ester (WCOME) from waste cooking oil collected from restaurants is by the transesterification process which is a process of using methanol (CH₃OH) in the presence of potassium hydroxide (KOH) as a catalyst to chemically break the molecules of Waste cooking oil into an ester and glycerol. The properties of WCOME, standard petroleum diesel and the ASTM standards for biodiesel are tabulated in table 1. The properties of WCOME fuel are similar to PD fuel. The viscosity of WCOME fuel is 5.75cSt at 40°C which is higher compared to diesel. The higher viscosity of WCOME is a major problem to use in the engine because of poor flow characteristics. To reduce the viscosity preheating is done. The arrangement used for preheating of fuel for this study is shown in the figure 1. It consists of small diameter copper tube through which the fuel is allowed to flow, water tub in which copper tube is immersed. An inlet of copper tube is connected to fuel tank and outlet to fuel pump. The water in the tub is heated by an electric heater which is controlled by a dimmer stat. At the outlet of copper tube a thermocouple is attached to measure fuel temperature.

Table 1: Properties of Fuels

Property	Unit	PD	WCOME	ASTM Standards.
Density	g/cc	0.831	0.88	0.87-0.89
Kinematic Viscosity at 40°C	cSt	2.58	5.75	1.9-6.0
Flash Point	°C	50	162	130 min
Fire Point	°C	56	170	-
Calorific value	kJ/kg	42500	39620	37500



Figure 1: Preheating Setup

The variation of viscosity with the temperature is shown in the figure 2. The viscosity WCOME at 50°C is almost nearer to viscosity PD at 30°C. The preheated WCOME (PHWCOME) viscosity at 50°C is almost equal to diesel at 30°C and hence PHWCOME may exhibit similar flow characteristics as that of PD. This indicates that the preheated WCOME can be used in a diesel engine without any modifications to acquire similar characteristics as PD and used as alternative fuel.

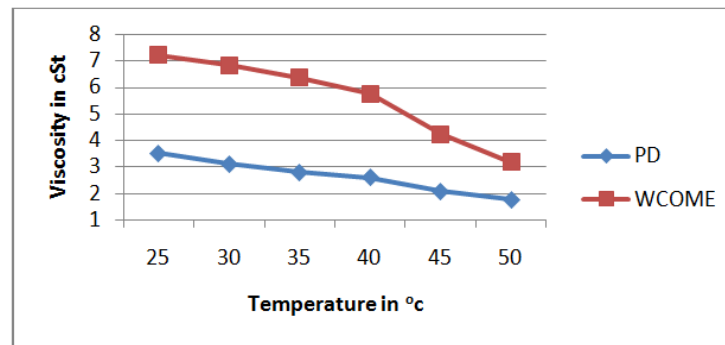


Figure 2: Variations of Viscosity of Fuel with Temperature

Experimental Setup and Testing

The engine used in this work is a Kirloskar make constant speed (1500 rpm) naturally aspirated single Cylinder water cooled stationery direct injection compression ignition (DI-CI) engine. The experimental setup consists of an Eddy current type dynamometer to measure engine load, Data acquisition system, display panel, gas analyser for exhaust gas measurement, thermocouple sensors for temperature measurement, pressure measuring sensor inside the cylinder. Throughout the test constant temperature and flow rate were maintained for the engine to obtaining good results. Table 2 shows the engine detailed specifications. The experimental set up used for this work is shown in the Figure 3. The emissions were analysed using gas analyser and its specifications are given in the Table 3.

Table 2: Engine Specifications

Make	Kirloskar Oil Engine
Engine	Single Cylinder DI-CI
Air admission	Naturally aspirated
Bore X Stroke	80 mm X 110mm
Compression ratio	16.5:1
Max power	3.72 kW @ 1500 rpm
Dynamometer	Eddy Current Dynamometer
Pressure sensor resolution	bar for cylinder pressure
Crank angle sensor resolution	1 degree
Type of Pressure sensor	Piezo electric type
Type of starting	Manual cranking
Method of cooling	Water cooled



Figure 3: Experimental Set Up

Table 3: Emission Gas Analyser Specifications

Exhaust Gas Analyser Make and Model: INDUS make and PEA 205		
	Range	Resolution
NO _x	0-5000 ppm	1 ppm
HC	0-15000 ppm	1 ppm
CO	0-15.0%	0.01%

To investigate the performance and emission characteristics, the engine was tested with waste cooking oil methyl ester (WCOME), preheated waste cooking oil methyl ester (PHWCOME) and baseline Petroleum Diesel (PD). Constant speed of 1500 rpm was maintained throughout the testing and the engine was allowed to warm up until all the temperatures reach steady state. An Eddy current dynamometer was used to measure the brake power (load). Four different loading conditions were considered for the study and they are 0.93kW (25% load), 1.86kW (50% load), 2.79kW (75% load) and 3.72kW (100% load). “Labview” software provided by the Tech-Ed Bangalore, India was used to record the necessary parameters.

RESULTS AND DISCUSSIONS

The DI-CI engine performance and emission characteristics, Brake Thermal Efficiency (BTE), Brake Specific Fuel Consumption (BSFC), Brake Specific Energy Consumption (BSEC), Indicated Mean Effective Pressure (IMEP), Peak Pressure, Exhaust Gas Temperature (EGT), un burnt Hydrocarbons (HC), Carbon monoxide (CO), and Oxides of Nitrogen (NO_x) were investigated and discussed as follows.

Brake Thermal Efficiency (BTE)

Figure 4 shows the variation in the Brake Thermal Efficiency (BTE) with the engine load of Petroleum Diesel (PD), waste cooking oil methyl ester (WCOME), preheated waste cooking oil methyl ester (PHWCOME). The BTE increases with the engine load for all the fuels. At full load the BTE for PD, WCOME and PHWCOME are 34.13%, 31.64% and 32.84% respectively. For PHWCOME, BTE is closer to PD due to reduction of viscosity with preheating, increased evaporation of fuel results complete combustion.

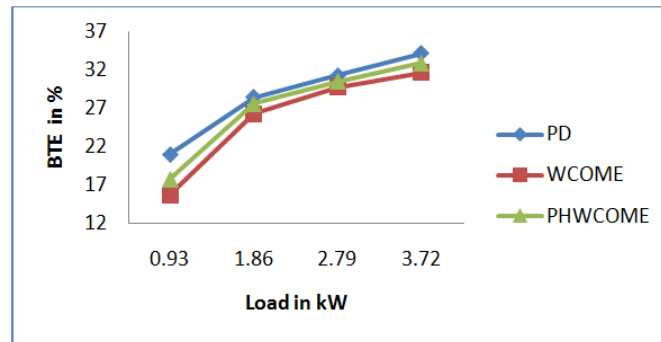


Figure 4: Variation of Brake Thermal Efficiency with Engine load

Brake Specific Fuel Consumption (BSFC)

BSFC variation for all the fuels with engine load is described in the figure 5. At all loading conditions BSFC of PHWCOME is lower than WCOME, but when compared to PD both fuels WCOME and PHWCOME consume more quantity fuel to produce unit kW of power. This is mainly due to the lower energy value of WCOME. But, from figure it is observed that BSFC of PHWCOME are very close to PD compared to WCOME at all loading conditions. It is also observed that the fuel consumption decreases with the preheating and is mainly due to improved fuel spray characteristics by lowering viscosity.

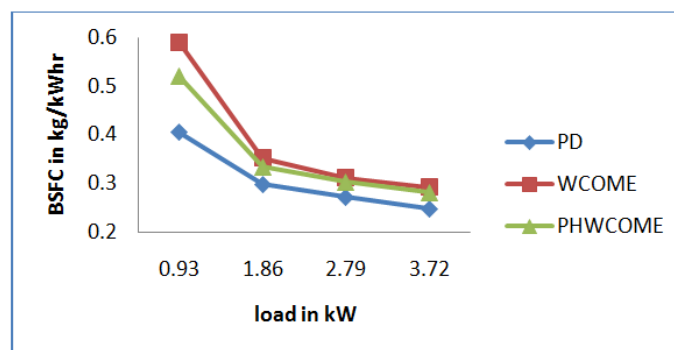


Figure 5: Variation of Brake Specific Fuel Consumption with Engine load

Brake Specific Energy Consumption (BSEC)

The input fuel energy requirement to produce unit brake power output is referred as Brake Specific Energy Consumption (BSEC). Figure 6 shows the variation of BSEC with the engine load for all the fuels. Decreased BSEC is observed for all the fuels with an increase in the engine load. BSEC of PHWCOME is lower than that of WCOME at all loads and closer to PD. The favourable results of PHWCOME compared to WCOME may be due to the high rate of evaporation and effective atomization of fuel with preheating condition.

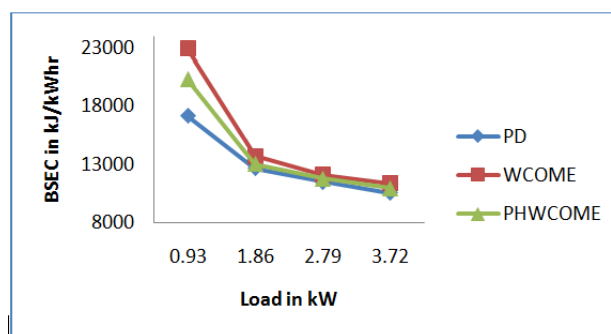


Figure 6: Variation of Brake Specific Energy Consumption with Engine load

Indicated Mean Effective Pressure (IMEP)

IMEP indicates the available mean pressure of combustion products inside the engine cylinder. The variation of IMEP with engine load is shown in the figure 7. From the graph it is observed that IMEP increases with an increase in the engine load for all the fuels. PHWCOME IMEP is higher than PD and WCOME at all power outputs. At full load, IMEP of PD, WCOME and PHWCOME are 8.62, 8.02 and 11.86 bars respectively. More oxygen content and advanced combustion with preheating leads to the development of higher pressure in the cylinder

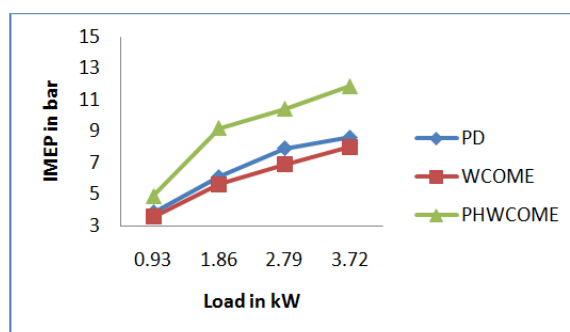


Figure 7 Variation of Indicated Mean Effective Pressure with Engine load

Peak Pressure

The variation of peak cylinder pressure on the bars with power output is described in the Figure 8. The peak pressure of PHWCOME is higher than PD and WCOME. The highest peak pressure of 66.2 bars is observed for PHWCOME at 2.79 kW engine load. The higher cetane number and early start of combustion of PHWCOME resulted higher peak pressure inside the cylinder nearer to TDC compared to other.

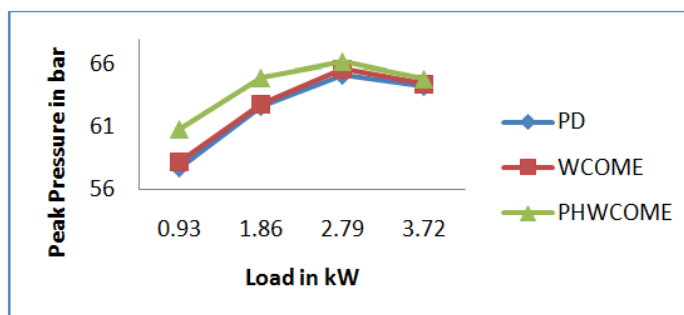


Figure 8: Variation of Peak Pressure with Engine load

Exhaust Gas Temperature (EGT)

Figure 9 presents the variation of exhaust gas temperature of fuels as a function of the engine load. WCOME and PHWCOME records very close exhaust gas temperature for all the engine loading conditions which are lower than PD. The lower the exhaust gas temperature of WCOME and PHWCOME is mainly due to a low calorific value of WCOME. With preheating the exhaust gas temperature slightly increased, but they are still lower than PD.

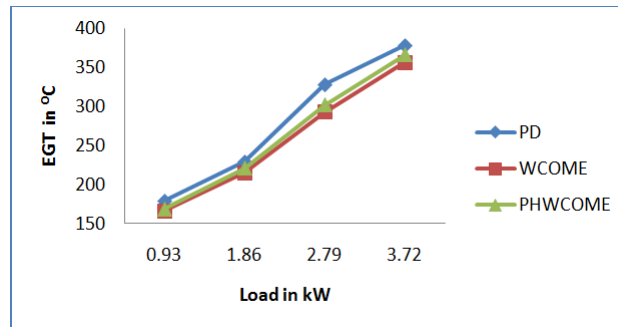


Figure 9: Variation of Exhaust Gas Temperature with Engine load

CO Emissions

For all the fuels, figure 10 shows the variation of CO (%) with the engine load. The increase in the CO emissions results with an increase in the engine load for all the fuels is observed. The increase in fuel consumption and knock with the engine load may be the reasons for the increasing trend of CO emissions. The CO emission levels are less for WCOME than diesel (PD). The further reduction in CO emission levels is observed for PHWCOME and are due to increase in the rate of evaporation and reduced viscosity & density.

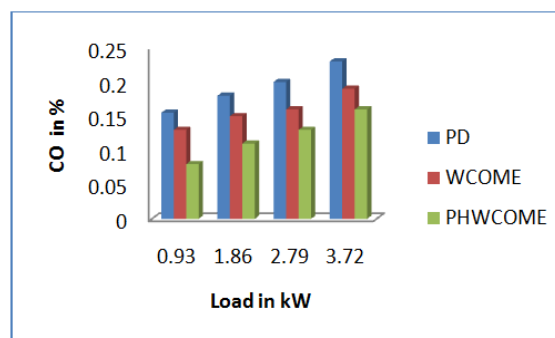


Figure 10: Variation of Carbon Monoxide with Engine Load

Unburned HC Emissions

The variation of unburned hydrocarbon emission (HC) of PD, WCOME and PHWCOME with respect to the engine load is shown in the Figure 11. The HC emission of WCOME (with and without preheating) is less than that of petroleum diesel (PD). The oxygen present in the biodiesel fuel led to an effective combustion might be the reason for low HC emissions. It is also observed that the emissions are further reduced for PHWCOME. But for all fuels the HC emission increases with power output.

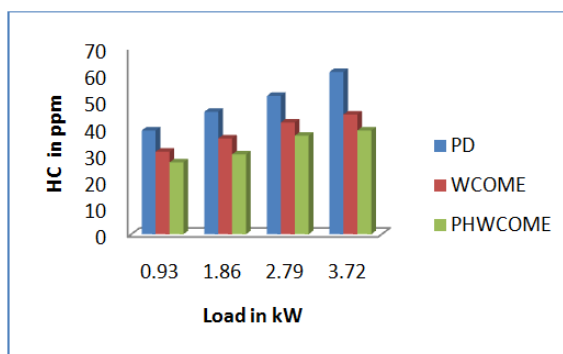


Figure 11: Variation of Hydro Carbon with Engine load

NOX Emissions

The NO_x emissions of fuels with the engine load are clearly shown in the figure 12. The increased NO_x emissions are observed with engine load for all fuels. The high NO_x emissions are observed in WCOME compared PD. Reduced NO_x emissions are observed for PHWCOME compared WCOME at all engine loads. It is also observed that NO_x emission levels of PHWCOME are very closer to that of PD.

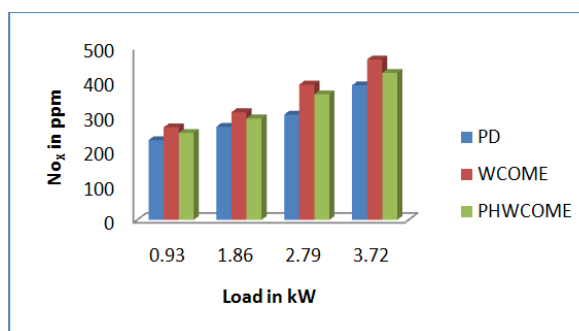


Figure 12: Variation of Oxides of Nitrogen with Engine load

CONCLUSIONS

DI-CI diesel engine characteristics were studied successfully with the preheated waste cooking oil methyl ester and results obtained were compared with the standard petroleum diesel operated characteristics. The conclusions drawn from this study are as follows

- Brake thermal efficiency increases with the engine load for all the fuels. WCOME BTE was lower than petroleum diesel, but BTE was increased with PHWCOME significantly. At the full engine load BTE of PHWCOME is 3.8% higher than WCOME. The increase in BTE with PHWCOME was due to reduced viscosity and improved fuel atomization characteristics. At 3.72kW engine load the BTE of WCOME, PHWCOME and PD were measured as 31.64, 32.84 and 34.13% respectively.
- BSFC and BSEC are decreased for all the fuels with the increasing engine load. At 3.72 kW loads these values are less for PHWCOME as compared to WCOME. The improved fuel flow characteristics with preheating improve the combustion process and resulted in complete combustion of fuel elements may be the reasons of lower BSFC and BSEC. But compared to PD, PHWCOME BSFC and BSEC values are slightly higher. The calorific value of PD is higher than WCOME is the reason for that.

- The peak pressure inside the cylinder is more for PHWCOME compared to PD and peak pressure attainment was also nearer to TDC for PHWCOME. This may be due to the higher cetane number and early start of combustion of PHWCOME of fuel when compared to normal PD. The exhaust gas temperature at all engine loads were also lower for PHWCOME than PD.
- There were significant reduction in CO and HC emissions with PHWCOME compared to PD. The reduction in CO emissions is 17.3% and 30.4% respectively for the fuels WCOME and PHWCOME compared to PD at full load conditions. 26.2% and 36% reduction in HC emissions were obtained with WCOME and PHWCOME fuels compared to PD at full load conditions. The preheating of fuel improves fuel flow characteristics and combustion process resulted reduction in CO and HC emissions.
- The NO_x emissions of WCOME and PHWCOME fuels increased by 19.2% and 9.2% respectively at full engine load compared to PD. This may be due to availability of more oxygen and increased temperature in the cylinder during combustion.

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